Zooplankton Aggregation Near Sills

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LONG-TERM GOALS

Improved knowledge of the physical and biological mechanisms and interactions responsible for forming and maintaining aggregations of biological sound-scatterers in the ocean.

OBJECTIVES

Dense aggregations of plankton and fish often occur in localized regions where ocean currents interact with steeply-sloping bottom topography. These aggregation sites are ecologically important 'hot spots' for prey-predator trophic interactions, and are also zones of very strong acoustic backscatter. Our project will examine the biological and physical oceanographic mechanisms responsible for forming, maintaining and dispersing these aggregations.

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APPROACH

We are combining retrospective analyses of existing acoustic and physical oceanographic data (the major effort in year 1, Trevorrow's responsibility in year 1 under a separate award #) with new field measurements (years 2 and 3). In both cases, our approach is multidisciplinary, linking the well-resolved spatial distributions provided by the acoustic data with the interpretive capability provided by the *in situ* physical and biological measurements. Sampling tools include: multi-frequency acoustics to measure cross-sill vertical sections of the back-scatter intensity and horizontal velocity (drift + swimming); an instrumented multiple plankton net (BIONESS) for zooplankton abundance, species composition, and body size/shape; and a high resolution digital camera for zooplankton body/swimming orientation.

Choice of study site is another important element of our approach. Aggregations of sound scatterers have been observed associated with a variety of bathymetric 'edges', including continental shelf break and slope regions (e.g. Simard and Mackas 1989; Mackas et al. 1997; Swartzman et al. 1999) and the margins of shelf banks and basins (Coyle et al. 1992; Haury, Briscoe and Orr 1979), submarine canyons (Allen et al. 2001, Greene et al 1988, Mackas et al. 1997), seamounts, and the edges, sills and headwalls of steep-sided inlets (Simard et al. 1986, Simard and Lavoie 1999, Romaine et al. in press). However, most of the above settings are hydrodynamically complex. To aid observation and understanding of interactions between flow field, bathymetry, and biology, we have selected as our study site the region surrounding the Knight Inlet fjord sill. This site provides (at least by oceanic standards) a very well-defined observational environment: strong cross-isobath flow that is predictably time-varying at semidiurnal, diurnal and fortnightly time scales, weak along isobath flow, clearly identifiable upstream and downstream locations and populations. There is also a wealth of previously collected acoustic and physical oceanographic information from previous research programs (e.g. Farmer and Armi 1999)

Expertise and project responsibilities of the lead investigators are as follows.

- D. Mackas is a biological oceanographer and zooplankton ecologist with expertise on zooplankton spatial pattern. He is responsible for net tow sampling of zooplankton, and will assist with the multi-frequency acoustic surveys.

- M. Trevorrow is an acoustician and physical oceanographer. He is responsible for retrospective analysis of older acoustic transects, and for acoustic measurements on the upcoming new field surveys.

- M. Benfield is a biological oceanographer and zooplankton ecologist with expertise on optical imaging methodologies. He will be responsible for measurements with the high resolution digital camera, and will assist with collection and interpretation of other zooplankton data.

- D. Farmer is a physical oceanographer and applied acoustician. He is providing interpretation of Knight Inlet physical oceanography, and access to data from prior surveys.

WORK COMPLETED

The first year of the project (Jan-Sept 2001) has been a start-up phase consisting of four activities:

1) Retrospective analyses of acoustic data from earlier surveys of Knight Inlet (Trevorrow, award #N00014-01-1-0273). This is the major line item in the overall year 1 budget; see *Results* section for scientific output.

2) Acquisition and testing of instruments for the field surveys to be completed in years 2 and 3. We have obtained and field-tested a new three-frequency downward-looking echosounder (40 KHz, 100 KHz, 200 KHz) that is based on a separate system previously developed by the Farmer lab. We have also added an Optical Plankton Counter (Focal Technologies OPC) to our BIONESS multiple net sampler.

3) Planning of, and booking of ship time for, the first of the new field surveys. We will be at sea on the CCGS VECTOR 12-26 November 2001.
4) Benfield (under separate funding) has continued development of his digital camera system.

RESULTS (RETROSPECTIVE ANALYSES OF PRIOR ACOUSTIC SURVEYS IN KNIGHT INLET)

1. Physical setting

The outer part of Knight Inlet is a fairly straight, uniform-width channel that runs approximately east-west. In the middle of this, near a point of land called Hoeya Head, there is a sill (approximately north-south) with sill depth near 60 m. The profile over the sill is asymmetric, with the western side steeper than the eastern side, and the crest of the sill is nearly flat. On the western side the sill falls away to about 150 m, while on the eastern side the depth reaches more than 400 m. The inlet has mostly semi-diurnal tides (strong fortnightly modulation), with tidal range from 1 to 4.5 m. The flood tide runs eastward. There is strong near-surface stratification, with a warmer, fresher surface layer 8 to 12 m deep. Gradients across the interface can be very strong (2 degrees, 15 psu, 15 sigma-t).

2. Daytime distribution of high-frequency sound-scatterers under differing flow conditions

i) far away from the sill and at all tidal phases, the zooplankton are concentrated within a layer typically between 80 and 110 m depth. A few early morning transects (around dawn) show this layer shallower, near 30 to 50 m, with the depth subsequently quickly increasing with time suggestive of downward vertical migration. There are also some intense scattering layers near the surface, possibly of biological origin.

ii) on the flood tide (Fig1), there is a strongly sheared internal hydraulic flow over the sill. Typically a flow bifurcation appears over the eastern edge of the sill, with a strong downward jet extending from about 15 m depth right down the eastern slope. Upstream the zooplankton layer is trapped against the steep western slope, forming a dense cloud. On the downstream side, the zooplankton layer re-forms itself east of the outlet of the downwelling jet. There is some more tenuous scattering in the strongly sheared flow boundaries that is more likely microstructure-induced scattering

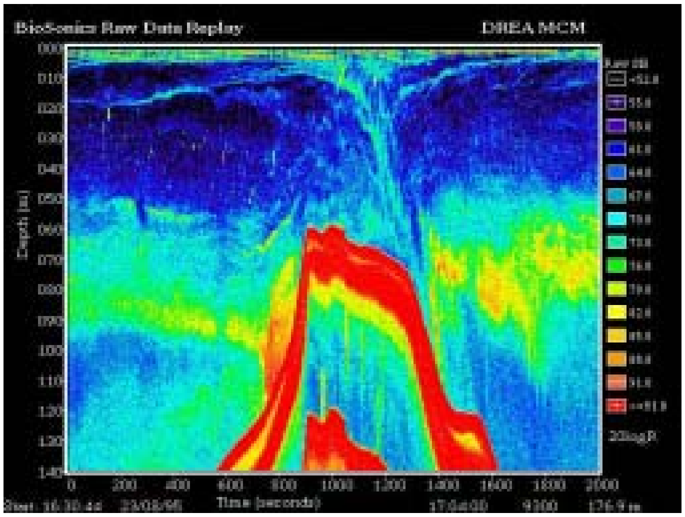

Fig 1. Horizontal and vertical distribution of acoustic back-scatter across the Knight Inlet sill during flood tide conditions (flow from west to east = left to right). The scattering layer is strongly intensified (suggesting accumulation) adjacent to the upstream (left) side of the sill. The layer is disrupted over the sill, then reforms downstream of a downwelling hydraulic jet.

iii) on the ebb tide (Fig 2), the situation is a rough mirror image, however the upstream trapping is less dramatic due to the more gradual eastern slope. A similar flow bifurcation always forms over the sill, but the strong downwelling jet only forms at the strongest point of the highest tides. The image shows the more typical situation where the bifurcation only extends downwards to 30 m or so. There may even be an overturning vertical gyre in the lee of the sill crest, trapping zooplankton below. As the ebb tide weakens and turns, the flow bifurcation is released upstream, often forming an internal bore that propagates eastward.

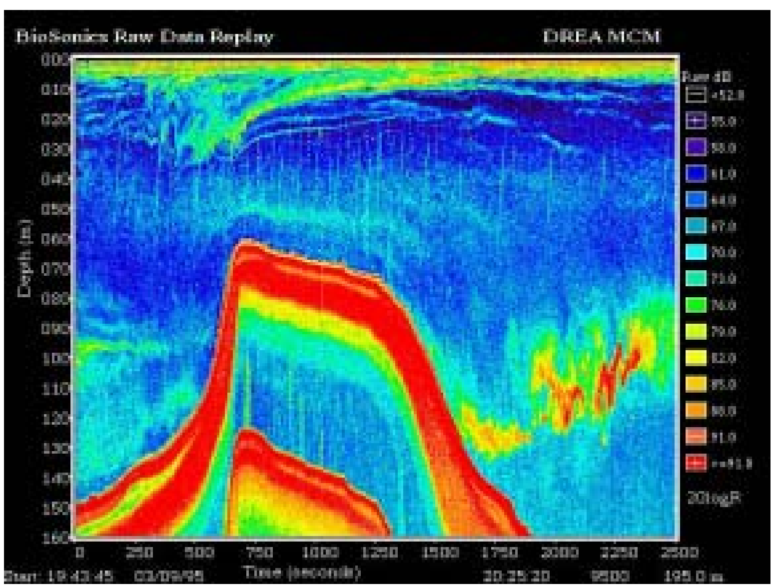

Fig. 2. Horizontal and vertical distribution of acoustic back-scatter across the Knight Inlet sill during ebb tide conditions (flow from east to west = right to left). The scattering layer is again intensified (suggesting accumulation) adjacent to the upstream (right) side of the sill. The layer is disrupted over the sill, then reforms downstream of the sill.

IMPACT/APPLICATIONS

This is a new project, and the bulk of the data collection and interpretation remains to be done. However, we expect that our upcoming field surveys (Nov 2001 and autumn 2002) will allow us to test hypotheses about zooplankton aggregation and transport mechanisms that have been suggested by the above observations. Once established for a relatively simplified flow regime, these can then be applied broadly to other regions with more complex flow patterns

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